Efficient Image Processing and Machine Learning Approach for Predicting Retinal Diseases

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We would like to dedicate this thesis to our loving parents ...

Declaration

It is hereby declared that this thesis /project report or any part of it has not been submitted elsewhere for the award of any Degree or Diploma.

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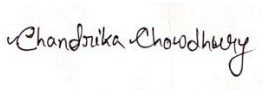

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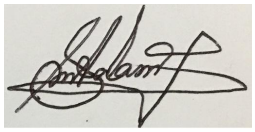

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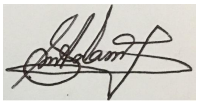

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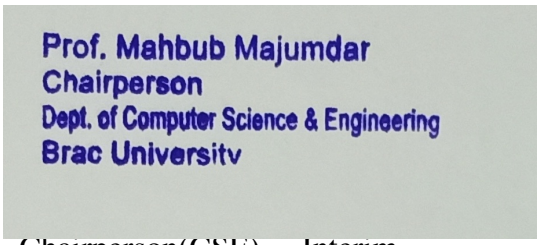

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Abstract

As the computational technology and hadrware system improved over time, the use of neural network in image processing has become more and more prominent. Soon deep learning also caught the attention of the medical sector and started getting used in classify diseases. Lots of research are currently going on to predict retinal diseases using deep learning algorithms. However, very small amount of research have been conducted on predicting choroidal neovascularization (CNV), Diabetic Macular Edema (DME) and DRUSEN. In this paper, we have classified OCT images into 4 categories (CNV, DME, DRUSEN and natural retina) by using two deep learning algorithm (convolutional neural network and artificial neural network). Before passing the images into the neural network, we have performed a number of preprocessing methods on the images. Furthermore, we have implemented different model for each algorithms. Each model has varying numbers of hidden layer attached to it. After completing our research we have found out that, convolutional neural network with four hidden layers outperforms all other neural network model by quite a big margin and generates 0.86 accuracy.

Keywords: Image Processing, Deep Learning, Neural Network, Convolutional Neural Network, Artificial Neural Network, Retinal Disease

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Chapter 1

Introduction

1.1 Background

As soon as, the technology of scanning and loading a picture in a computer were available, researchers started to build system capable of analyzing them. With the advancement in twenty first century, the system evolved from rule based system to machine learning technique. This techniques still play an important role commercially available medical image analysis systems[1]. However, one of the major drawback in machine learning techniques is that, all the feature used in the algorithm are generally hand written by an expert. The next step in image processing is to create algorithm which will by themselves be able to extract features and complete calculation. Hence, the introduction of deep learning in image processing is committed. Deep learning algorithms such as Artificial Neural Network and Convolutional Neural Network thrive in image processing field because of the availability of huge amount of imagery data.

Like other sectors, medical research also generates huge amount of image data in form of X-ray and other types of image report of particular organ. With the advancement of technology, researcher were able to take clearer picture images of inner organs as well. As a result, it was only a matter of time since deep learning techniques got the attention. The researchers started to use deep learning algorithm in various field of medical research such as retinal disease prediction [2], cancer prediction [3], abdominal musculoskeletal prediction [4] etc.

Deep learning is a branch of machine learning where different type of neural network are used for prediction and classification. With the advancement of modern technology and

computational algorithms, deep learning is used over huge dataset for classification and regression. Some of the popular deep learning techniques are, Artificial Neural Network (ANN), Convolutional Neural Network (CNN), Recurrent Neural Network (RNN), Long Short Time Memory (LSTM) Neural Network and etc. Below we discuss about some key concepts, techniques and algorithm used in neural network.

Neurons[7] are the building blocks of a neural network. It resembles biological neuron cells inside our brain. Neural Networks contains multiple layers of neuron. First Layer is called input layer and the last layer is called hidden layer. All the layer inside the input and output layer is called the hidden layer. Each neuron in the input layer takes a single feature from the dataset as an input and passes the value to the hidden layer. Every in neuron in a hidden layer is connected with its previous and proceeding layers neuron through weights. When a signal is passed to the hidden layer neuron from its previous layer, it multiplies each neuron signal with the corresponding weights and then add them all. After that the summation is passed through activation function to determine whether that hidden layer neuron will pass the signal to the next layer or not.

In Figure: 1.2, we can see the architecture of a neural network. Here, x1, x2. . . . . xn represents the feature input from the dataset, w1,w2 . . . . wn represents the weight correspond with each vector and f(a) represents the feature vector.

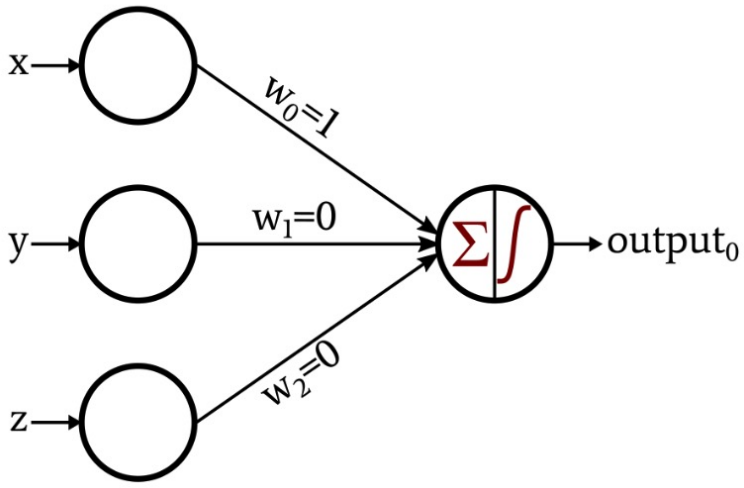

Fig. 1.1 A single Neuron [8]

At the very beginning weights are randomly assigned to the neurons. While at training these values get updated. By updating the values in the weights neural network learn to distinguish one object from the other. Another important factor while using the neural network for classification and regression is the number of hidden layer to be used in the

model. Generally the experiment based approach is used to the number of hidden layer. Which mean is that, models with varying numbers of hidden layer is used for the same dataset. The model that generates optimal result is selected.

Backpropagation is the technique which made deep learning so much popular this days. It is a learning technique used for neural network in supervised learning. This technique enables neural network to learn feature from a dataset without the intervention of human.

1.2 Research Problem

In this thesis we proposed and demonstrated a image processing approach using deep neural networks based on Artificial Neural Network and Convolutional Neural Network that allows categorizing retinal image images into different disease classes.

1.3 Research Objective

The purpose of this research is to develop an optimal deep neural network model which will able to predict retinal diseases by observing retinal images with higher accuracy. The objective of this research is,

- To find out an optimal neural network algorithm.
- Improve the neural network model.

1.4 Scope and Limitation

Retinal diseases cover an important sector in the medical research. Some of the common Retinal diseases that frequently occur are retinal tear, retinal detachment, diabetic retinopathy, glaucoma etc. With the advancement of hardware sector, doctors are now able to take clear images of retina. As a result, a huge amount of imagery data is now available to medical database by using which accurate predictions can be made. There are already some research where the researchers have used different type of machine learning and deep learning algorithm to predict retinal diseases.

1.5 Thesis Report Outline

The following paper is divided in five section. First section contains a brief introduction and necessary definition of important concept in our research. We believe that this will make understanding easier for our reader. In section 2 we have discussed about some of the previous research completed in this sector. In section 3, we have discussed about our dataset and methodology followed to come to the conclusion. We have presented our result in Section 4. A discussion on the result is also added into that section. Finally, in Section 5 we have concluded our paper and briefly talked about the possible future work on this topic.

Chapter 2

Literature Review

In their paper [12], authors have collected various feature by examining Retinal Nerve Fiber Layer (RNFI) and Visual Field (VF). They have taken another step further and extracted synthesized feature from those original features. After that, they used three popular machine learning algorithms, namely Random Forest, Support Vector Machine and K Nearest Neighbor. However, one of the major shortcoming of their research is that, the dataset they have used is very small in size. It contains only 100 rows for testing and 399 rows for training and validation. As we all know, Deep learning requires large dataset to predict accurately.

In another paper [13], researchers used convolutional neural network to detect Glaucomatous Optic Neuropathy by measuring color fundus images. They used a dataset of 48,000 images and asked experts to label the data. After that they used convolutional neural network to classify the images. In paper was a key inspiration for us. Our work differ from this paper in two ways, 1) we used two different deep learning algorithm (CNN and ANN) and compared between the result and 2) We used a much larger dataset.

Researchers also has used deep convolutional neural network in detection of diabetic retinopathy by using fundus images of retina [14]. They have used a dataset consisting 127125 images of the retina and those images have been graded by 54 licensed ophthalmologists. However, they only focuses on one single disease and have used fundus image rather than OCT images like us.

Another influential paper in the field [15] talks about multiple classification of retinal diseases such as age-related molecular degeneration, diabetic retinopathy, macular bunker, retinoblastoma, retinal detachment, and retinitis pigmentosa. This paper uses deep convolutional neural network and SVM classifier to classify images in to different disease category.

Furthermore, they also talk about how the relatedness of the diseases makes it harder to classify them.

Furthermore, in this paper [16] researchers used oct images to classify images into different categories of diseases. Like us they also used a form of convolutional network and compared the result the human ophthalmology experts classifying them.

In another study [17], researchers have used deep learning to predict Age-related macular degeneration (AMD). They have used 120, 656 color fundus images and defined 13 classes for the prediction. In the choice of deep learning algorithms, they have tried various combination of convolutional neural networks. One ensemble of six different neural network has improved the accuracy to 94.3. However, they have only classified images for only one disease and used fundus images as a dataset.

In this paper [18], researchers tried to classify images to detect glaucoma. They separated the output into two class, glaucoma and not glaucoma. After that, they used unsupervised convolutional network to find out features from raw images. Later, they have run a Deep Belief Network (DBN) over the features and tried to find out the best feature to be used in research. Finally, they used softmax to classify object for the two different class.

In this paper [19], the researchers also have used deep learning network to predict cardiovascular risk factor in retina by using retinal fundus images. They have trained their model in a dataset containing 284.335 images from patients of different age group and validate their findings in two independents datasets. One containing 12,026 images and another 999 images. However, we believe that, they should have used a much larger dataset to validate their findings.

In another paper [20], researchers have talked about various deep learning algorithm that can be used to predict diabetic retinopathy in someone retina. This is a review paper. On this paper, the authors also have talked about different papers where the researchers have used deep learning algorithms and generated better prediction value. Although this is not a typical research paper, where the author introduce a new model and try to validate their claim, this paper can be used as a basis in order to conduct further research.

Unlike the previous paper[21], authors from this paper [10] actually uses a deep learning algorithm to predict diabetic retinopathy in retina. They have used a small dataset however, consisting only 1796 retinal fundus images from one thousand six hundred and twelve diabetic patients. They have classified the images into three classes. However, we from our experience believe that, the number of images inside the dataset is very small for any neural network algorithm to perform at its best.

The second last paper [22] we are going to talk about here talks about fully automated detection system build by deep learning algorithm which deals with OCT images. The method they have described in their paper automatically detects IRC (Intraretinal cystoid) fluid and SRF (Subretinal) fluid. They have also used a dataset containing 1200 volume of OCT images.

The final paper [23] we are going to talk about talks about various deep learning technique used to detect diabetic retinopathy in people from different ethnicity suffering from diabetics. The interesting fact of this paper is that, not only they discuss about the different deep learning algorithms but also they have moved one step ahead. They not only used to image data available in the dataset, they classify them into different ethnicity. We all know that, people from different corner of the plant tends to display different food habit and food habit has a direct consequence on maintaining diabetics. By focusing on the ethnicity, these researchers has drown out a different aspect ignored by the others so far.

Chapter 3

Methodology

In our proposed method we used two different neural network CNN(Convolutional Neural Network) and ANN (Artificial Neural Network). In this section, we talk about step by step procedure we have followed in our research. There are 84,494 pictures in our dataset and we have divided them into three categories (Training, Validation and Test). 60,000 randomly picked pictures are used to train the model and 15,000 pictures are used to validate our training models. While remaining 10,000 pictures are used for testing. In this remaining section, we describe step by step procedure of our research procedure. In Fig: 3.1, we have represented step by step procedure of our research.Later in this chapter we have explained that flowchart step by step.

Input Data:

In the first step, we import our image folder in the algorithm. There are built in library in python to accomplish this task. There are four categories of images in the dataset. Three of those categories correspond to disease type and fourth category is normal retina. There are 84,494 pictures in our dataset and we have divided them into three categories (Training, Validation and Test). 60,000 randomly picked pictures are used to train the model and 15,000 pictures are used to validate our training models. While remaining 10,000 pictures are used for testing.

In here, we used OCT (Optical Coherence Tomography) which is an image capturing technique. By using OCT ,two or three dimensional images of the biological tissue can be captured. This technique uses low coherence light to take micrometer resolution.

Pre processing :

1.Image Resizing: It is technique used in neural network to reduce the pixel of any

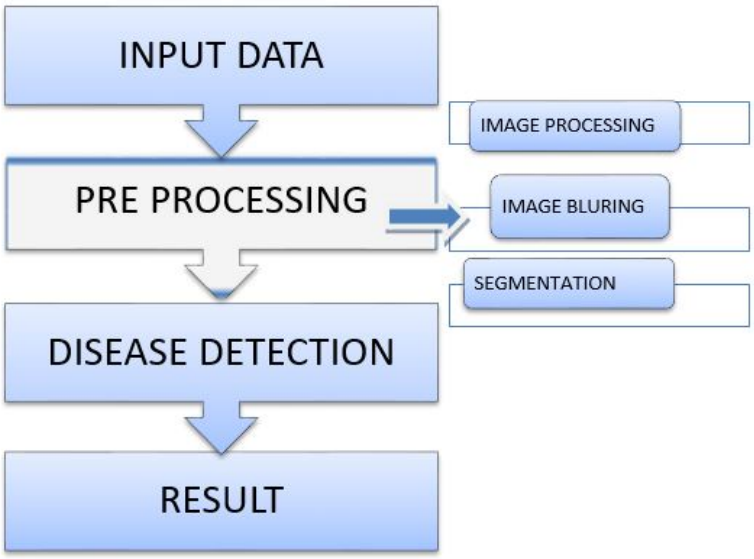

Fig. 3.1 Proposed Methodology

image to a certain size. As neural network such as CNN works with fixed number of feature over the complete dataset, it is necessary to preprocess the images into a fixed size. One of risk, regarding this technique is that valuable information might get loss. However, built-in nature of CNN, finding the hidden features, tread off with this shortcoming.

In this step, we resize all of the image. The reason behind resizing all the picture is that, to import every picture in neural network the size of all the picture need to be same otherwise the neural network might generate wrong output and misclassify elements. We have decided to resize all the picture in 200px by 200px. Because if we resize them any smaller valuable information might get lost and any higher dimension will cost neural network additional power drain and take longer to produce output. It also reduce dimensionality and make neural network faster in classification and regression task. We used python library for resizing images.

2.Image Blurring : This is also another important technique frequently used in image classification. Before inserting the images into convolution network it is necessary to get rid of unnecessary line and edges in the image. This might causes the neural network misclassify object. As a result, different type of image blurring techniques are used in image processing.

In this step, we remove the noise associated with each image. Generally, noise means different types of errors or unwanted pixels in an image. By removing this erroneous values we make our neural network more efficient. If there are noise present in the images, it might

Fig. 3.2 Resizing of retinal images

result into over fitting. We used “Gaussian Blur” technique to remove noise from the images. Gaussian blur technique is a technique where the Gaussian formula is used to blur the image and remove noise.

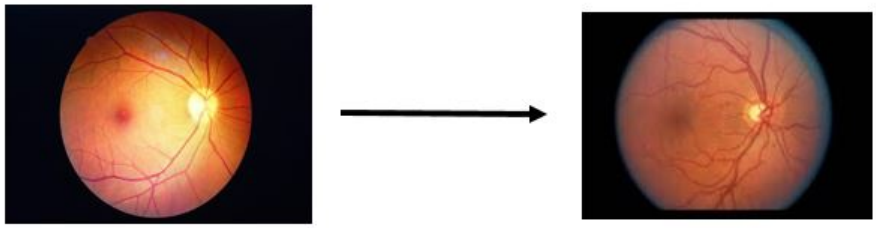

Fig. 3.3 Making retinal images blur

3.Segmentation: Image segmentation is the process where important objects inside an image is segmented for the better accuracy. In this process, certain object such as cat and dogs part of the picture got segmented from the complete image and neural network can focus on them for betterment of accuracy.

Even after removing the image, another important task is detecting important object in the image. There might be certain edges and line determining the importance of an object and this edges and line might be present in anywhere of the image. Segmentation is a popular technique to identify objects in an image. In our research, we remove unnecessary attention from the background and focus on the retina section of the picture. Also we blur the background for making neural network more accurate.

Disease Detection:

Retina [5] is a thin layer back of the eyeball in our eye. It contains cells that are sensitive to light. When light passes through retina, it triggers nerve impulses which later passes through optic nerves and create image on the brain. The cells that build retina is called cone

cells. They are a photoreceptor cells and functions to receive light signals. Generally there are 7 million cones in retina. Red cone cells contains 64 percent of them whereas green and blue cone contains 32 percent and 2 percent respectively. The total size of the retina is in between 30 to 40 mm in diameter.

Retinal diseases are the diseases that generally occur and harm retina. These diseases widely varies however shows visual symptoms. Some of the retinal diseases are,

- Retinal tear.
- Retinal detachment,
- Diabetic Retinopathy
- Epiretinal Membrane
- Macular Hole
- Macular Degeneration

In our research we have classified retinal images into four classes. Namely CNV, DME, DRUSEN and Normal retina. Using deep neural networks.

Artificial Neural Network[9] or (ANN) are most common type of neural network and said to be the pioneer of many deep learning algorithms currently used today. It is created by the multiple pieces of connected neurons. Each is stored in layers and connected through weights with the previous and proceeding layers of neurons. Different types of activation functions are used to activate a neuron and it only fires for a certain value of the activation function. Some of the popular activation functions are, sigmoid function, tanh function and Relu.

When initializing an artificial neural network random values are assigned to the weights of the neuron. Later with use of gradient decent and backpropagatioin a neural networks learns to classify objects into different classes.

Convolutional neural network[10] is a very popular form of deep learning used in image classification. It is inspired by the visionary system of human being and replicate the process for computers. Generally it consists of convolutional layer, max pooling and fully connected layer. Inputs are provided straight into the convolutional layer and filters and activation functions are used detect the hidden feature. Filters in each layers are used to more and more complex features of the dataset. Finally fully connected layers are used for final classification.

At the beginning random values are assigned to the weights and this weights are updated

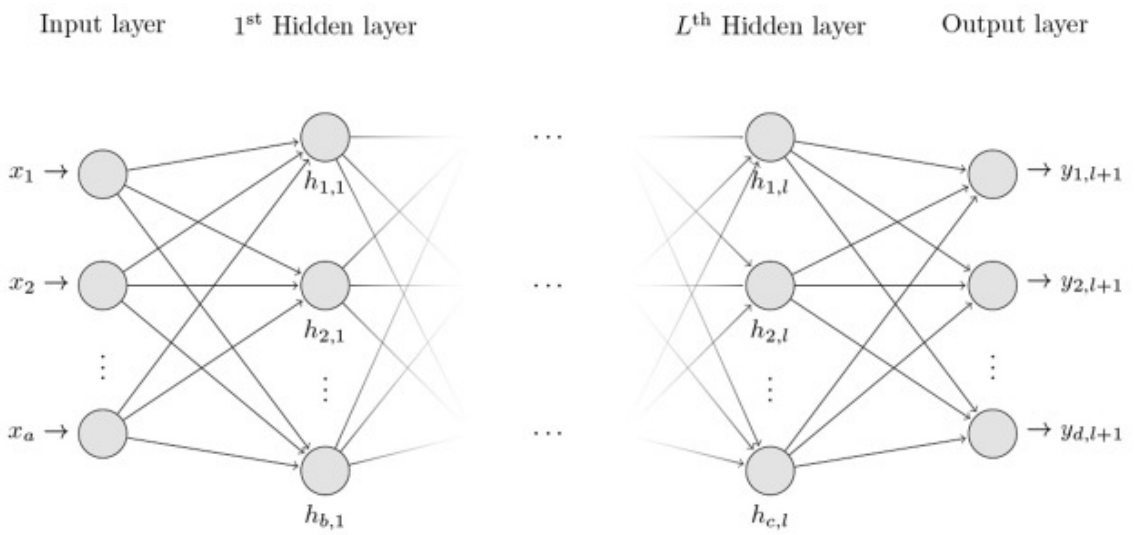

Fig. 3.4 Architecture of Artificial Neural Network [9]

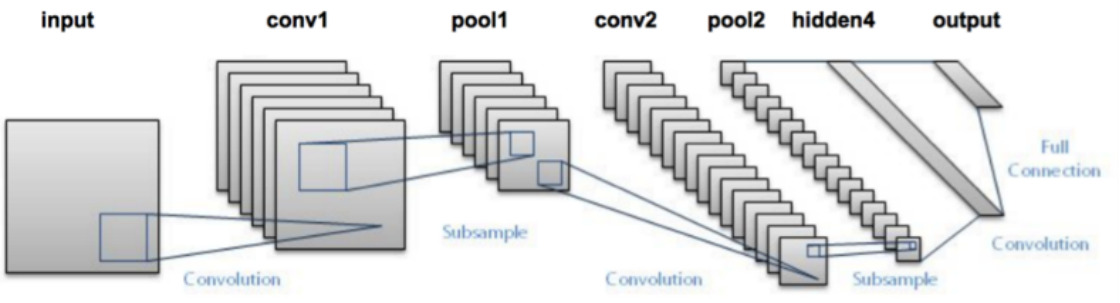

Fig. 3.5 Architecture of Convolutional Neural Network [11]

after multiple iterations in the training data. Provided enough example, convolutional neural network can predict with high accuracy for a population.

Result:

Finally in this last step, we compared the result from different neural network model. We have used two deep neural network, namely ANN and CNN. We have used three models for each neural network we have tried models with 3, 4 and 5 hidden unit. The input layer for every model consists input layer of 400 node as the images were 200px by 200 px in size.

Chapter 4

Result and Discussion

In this section we talk about the findings of our research. This section is divided into two part. In first subsection we talk about our dataset and in the second subsection we present our result.

4.1 Dataset Description

This dataset [24] contains 84,495 OCT (Optical Coherence Tomography) images of retina. The images are divided into four disease category. The diseases are,

1. Choroidal Neovascularization (CNV)
2. Diabetic Macular Edema (DME)
3. Multiple Drusen present in early AMD, and
4. Normal Retina

Images were selected from five institutes within a time span from July 1, 2013 to March 1, 2017. The institutes are

1. Shiley Eye Institute of the University of California San Diego,
2. The California Retinal Research Foundation,
3. Medical Center Ophthalmology Associates,
4. The Shanghai First People's Hospital, and
5. Beijing Tongren Eye Center.

Table 4.1 Comparison between different Neural Network Model

	Hidden Layer	Accuracy	Sensitivity	Specificity	Precision
CNN	3	80.62	79.78	80.65	80.08
	4	86.71	85.04	86.08	85.41
	5	84.93	83.28	84.50	83.12
ANN	3	72.80	71.71	72.96	72.43
	4	68.71	67.72	68.27	66.56
	5	74.76	73.95	74.37	72.63

Furthermore, experts were consulted before labeling the images.

There are four categories of images in the dataset. Three of those categories correspond to disease type and fourth category is normal retina. The three diseases are,

CNV : choroidal neovascularization is a disease that occurs on retina. There is a layer under retina named choroid. When people develop this disease new blood vessels start to grow in huge amount in choroid and then infiltrate the retina. Unlike normal vessels, this new blood vessels let fluids from blood and sometimes red blood cells into the retina. With time this fluid can harm retina by killing the light sensing cells.

DME : Diabetic Macular Edema or DME is one kind of a retinal disease that occurs because of fluid leaking in retina part name Macular. Generally this disease occurs to the diabetic patient and can damage blood vessels in the retina. If this disease is not treated in time, this blood vessels starts to create pressure in eye resulting in eye damage.

DRUSEN: DRUSEN are white or yellow colored spot occurs in retinal layer called Bruch's membrane. There are many reason that can lead to this situation. Most popular cause is gathering of waste products from rods and cons. If not treated at time this can lead to permanent blindness.

4.2 Result and Discussion

The main reason of conducting any research in any field is to find out new insights or challenge the already existed knowledge. In this subsection, we demonstrate our founding also discuss about it.

Table 4.2 Comparison of different Neural Network Model accrately predicting diseases

	Hidden Layer	CNV	DME	DRUSEN	Normal
CNN	3	80.43	78.77	81.53	79.80
	4	86.53	86.77	87.38	85.79
	5	83.32	84.35	81.17	84.21
ANN	3	71.20	72.23	70.57	71.34
	4	66.51	68.42	67.88	65.50
	5	73.77	75.11	73.73	75.93

4.2.1 Result

As mentioned earlier, we used two deep learning algorithm, namely Convolutional Neural Network (CNN) and Artificial Neural Network (ANN) in our research. We have experimented different umbers of hidden layer to find out the optimal model of algorithm. Furthermore we haven't selected any feature for the deep learning algorithms. The algorithms using their build in nature selected their own feature.

As shown in the table, we have measured the prediction quality in four categories. All of this functions generate a value between 0 to 1. Where if the value is closer to 1 it is considered to be a better algorithm.

Accuracy: In this category we divided total the correctly predicted value by the number of images.

$$Accuracy = \frac{P}{N} \tag{4.1}$$

where, P is the correctly predicted picture and N is the total number of images Sensitivity: Sensitivity is measured by dividing True Positive by the summation of true positive and false negative.

$$Sensitivity = \frac{TP}{TN + FN} \tag{4.2}$$

Where TF = True Positive, TN = True Negative FN = false negative

Specificity: specificity is measured by dividing true negative value with the summation of true negative and false positive.

$$Specificity = \frac{TN}{TN + FP} \tag{4.3}$$

Where TN = True Negative FP = False positive

Precision: Precision is measured by dividing true positive value with the summation of true positive and false positive.

$$Precision = \frac{TP}{TP + FP} \tag{4.4}$$

Where TP = True Positive FP = False Positive

4.2.2 Discussion

From the table: 1, we can see that, convolutional neural network with four hidden layer is producing the best result among all. Accuracy score of that particular model is 86.71. It is also providing us with sensitivity and specificity score of 85.04 and 86.08. Furthermore, it is also showing optimal score in precision with 85.41. Clearly this model outperform other models for this particular dataset.

In addition, we can see that, ANN with four hidden layers are performing worst among other model. It is generating only 68.71 accuracy with specificity and sensitivity score only 67.72 and 68.27 respectably. Its poor performance also can be seen in precision measure, where it is only generating 66.56.

However, as a whole, CNN algorithm is performing better than ANN. From the table we can see that, all of the CNN model are generating much better score than every model of ANN. This behavior is predictable because of the advanced build in mechanism of CNN. ANN is only using feedforward technique. As a result CNN outperforms ANN in every model.

In the matter of hidden layer, we believe that when we are using four hidden layers, CNN is creating more useful features than the CNN model which used only three hidden layer. On the other hand, when we are using five hidden layers additional noise is being created in the process, which in term affecting the accuracy of the model. As a result, CNN with four layers are generating the optimal result. However, as neural networks are black box algorithms, further experiments are necessary to completely validate our result.

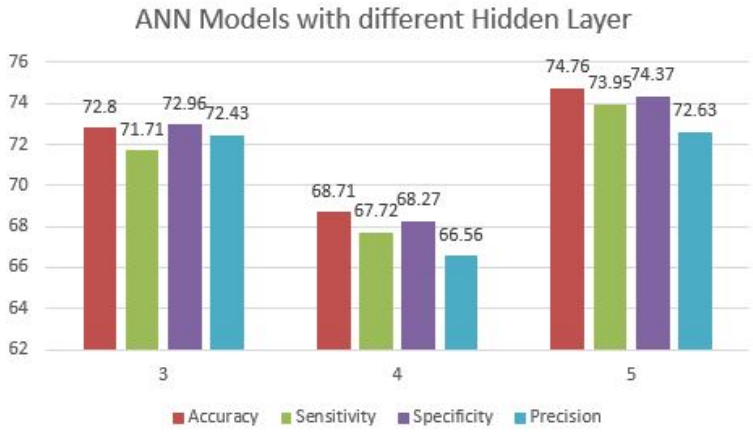

Fig. 4.1 Comparision of different ANN Models

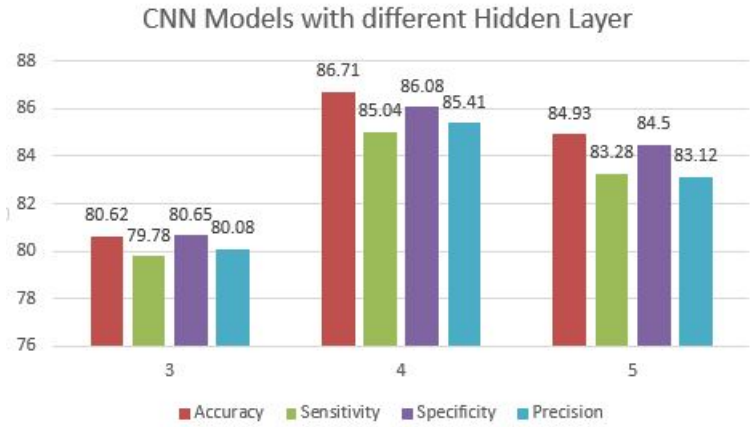

Fig. 4.2 Comparision of different CNN Models

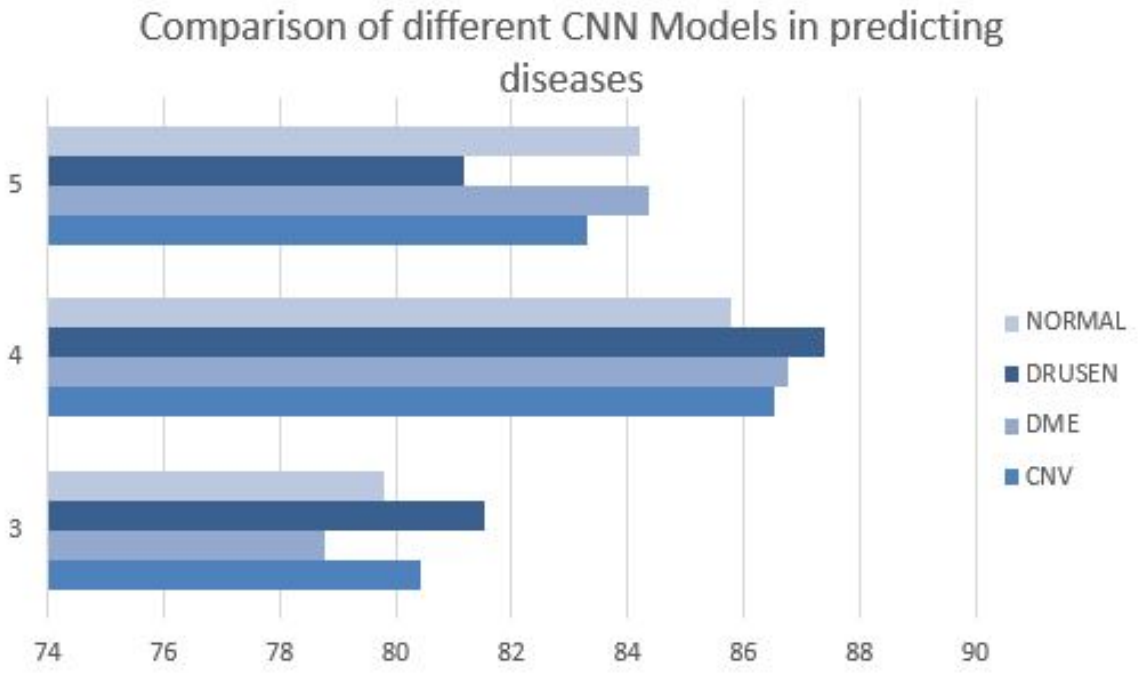

Fig. 4.3 Comparision of different CNN Models predicting diseases

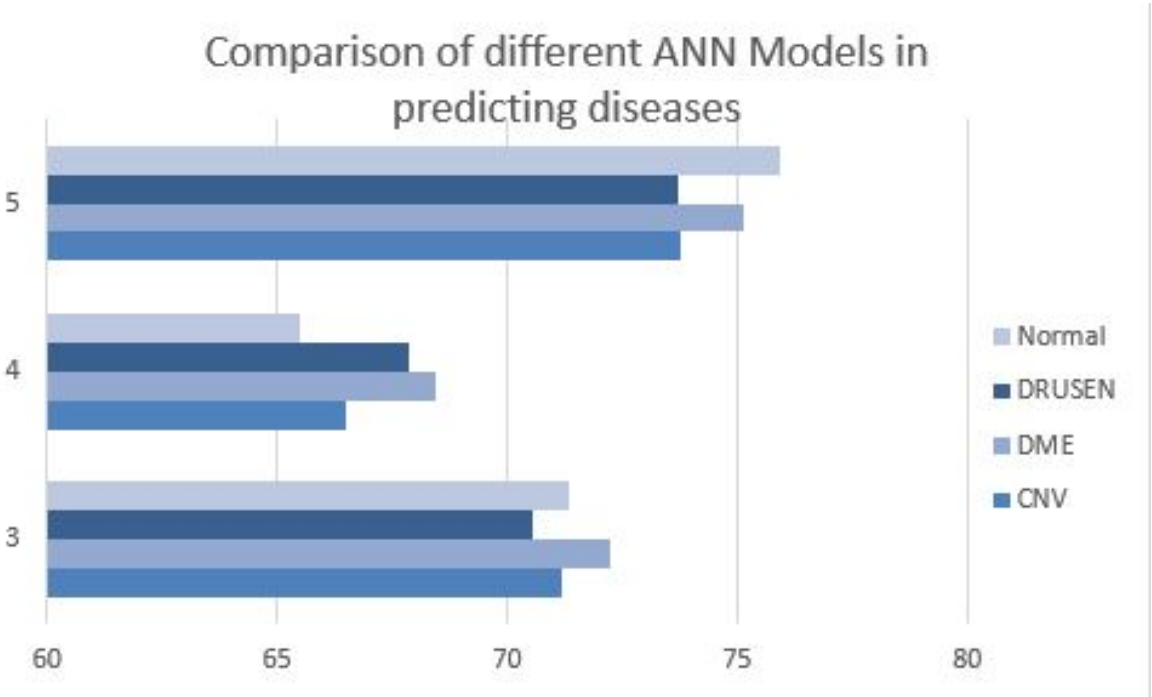

Fig. 4.4 Comparision of different ANN Models predicting diseases

Chapter 5

Conclusion

With the advancement of time, machine learning algorithm has outperform statistical models in a data analysis and data prediction. Algorithms such as Naïve bias, SVM and Decision Tree brought revolution in the field of computer science. However, as the amount of data increased over time limitation of this algorithms became more and more clear. That's when the deep learning algorithms join in the field. Even being a type of machine learning algorithm, deep learning algorithms are able to select features on their own and perform complex non-linear equation. As a result they quickly outperformed other machine learning algorithm in various field. Convolutional neural network has taken over image processing sector, where as Recurrent Neural Network (RNN) rules in Natural Language Processing field.

Like the other sectors, soon the importance of deep learning algorithm is felt by the researchers in that sector and they started using it in their research. As medical sectors generates tons of data in the form of image, it was convenient for the researchers to use those image for predicting existed diseases. Thus deep learning became popular in disease predictions. Researchers used deep learning to predict cancer, ophthalmology and many other sectors.

The medical sector which studies retina and eye diseases is called ophthalmology. Like other medical sector, it also generates tons of imagery data in the form of report picture. Researchers from this field, have used this images to predict diseases that might occur in eye.

In our research, we have taken inspiration from those researches and tried to separate three retinal diseases form the normal eye using two deep learning algorithm. Namely, Convolutional Neural Network and Artificial Neural Network. It turns out that, CNN outperforms ANN and generates an optimal result for the dataset we used in our research.

However, we would not want to stop our research in this spot. We believe that, we can improve the accuracy of the algorithm and we would like to use few more deep learning algorithm. Also we would like to use few more dataset on other diseases than ophthalmology. Furthermore, we would like to use unsupervised learning technique as well and try to see whether it outperforms our conventional supervise deep learning algorithms.

Chapter 6

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